

# Laser Surface Modification



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

# Outline

- Process Descriptions
- Mechanisms of Laser Surface Modification
- Applications



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

# Laser Surface Modification

- The laser has some unique properties for surface heating
  - The electromagnetic radiation of a laser beam is absorbed within the top atomic layers for opaque materials, such as metals
  - There are no associated hot gas jets, eddy currents or even radiation spillage outside the optically defined beam area
  - In fact the applied energy can be placed precisely on the surface only where it is needed

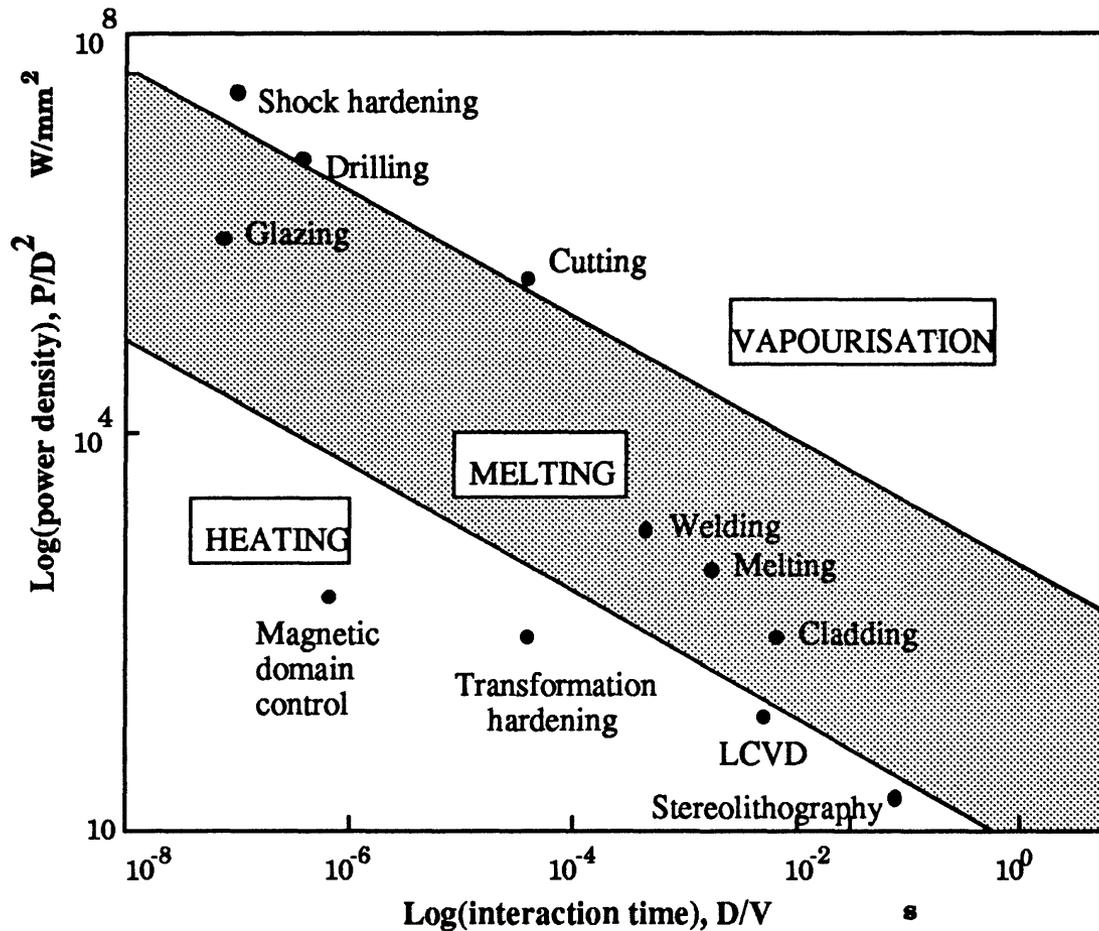


# Advantages

- Chemical cleanliness
- Controlled thermal penetration and therefore distortion
- Controlled thermal profile and therefore shape and location of heat affected region can be predicted
- Little-to-no finish machining is required
- Remote non contact processing is usually possible
- Relatively easy to automate



# Process Map



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

# Surface Modification

- Improved components with idealized surfaces and bulk properties
  - Particular parts of surfaces which are vulnerable to corrosion or wear confined to small areas
  - For large areas electroplating will be a better solution
  - for discrete areas the laser has few competitors and can yield wide variety of surface modification



# Surface Modification

- Surface heating for transformation hardening or annealing
- Surface melting for homogenization, microstructure refinement generation of rapid solidification structures and surface sealing
- Surface alloying for improvement of corrosion, wear or appearance
- Surface cladding for wear, corrosion or physical property manipulation such as melting point or thermal conductivity
- Surface texturing for improved paint appearance
- Plating by Laser Chemical Vapour Deposition (LCVD), Laser Physical Vapour Deposition (LPVD)



# Heat Source in Hardening

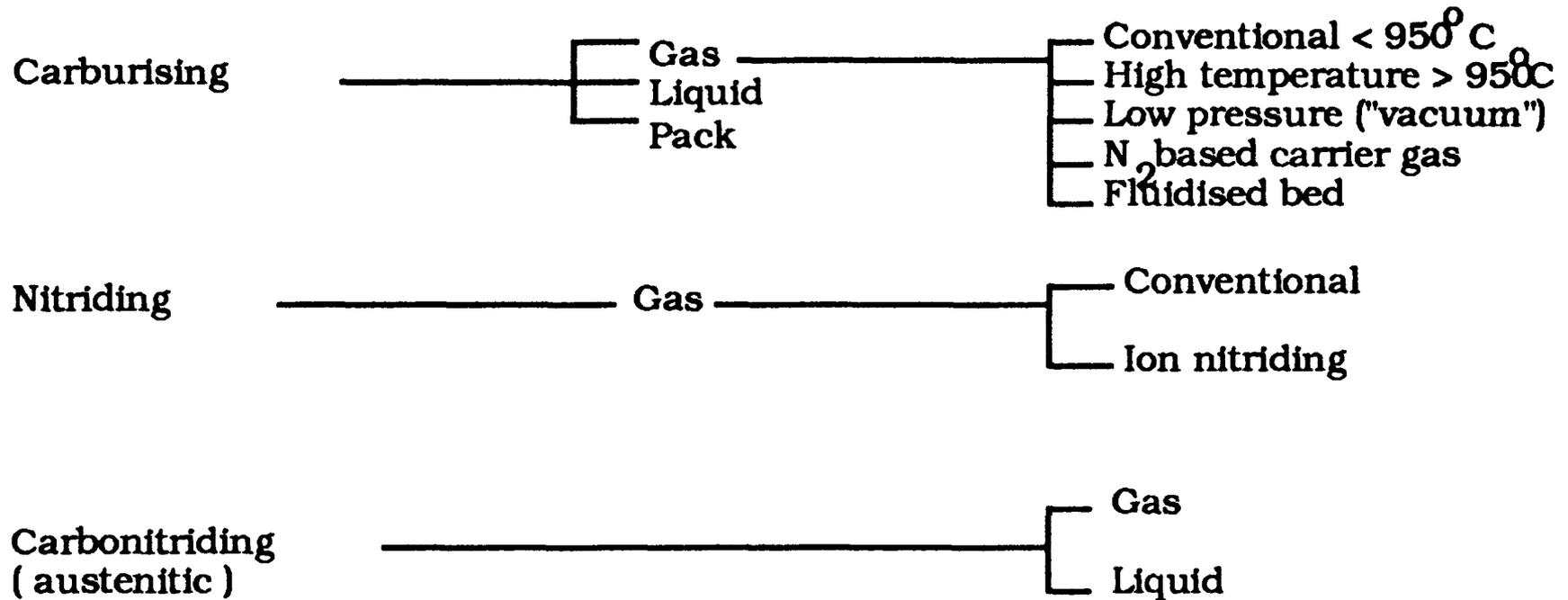
1. Heating Processes		
	Advantages	Disadvantages
Laser	<ul style="list-style-type: none"> <li>Minimum part distortion</li> <li>Selective hardening</li> <li>No quenchant required</li> <li>Thin case capability</li> <li>Case depth controllable</li> <li>Eliminates post processing</li> <li>Improves fatigue life</li> </ul>	<ul style="list-style-type: none"> <li>High equipment cost</li> <li>Coverage area restricted</li> <li>Absorbent coatings necessary</li> <li>Multiple passes give local tempering</li> </ul>
Induction	<ul style="list-style-type: none"> <li>Fast process rates</li> <li>Deep case obtainable</li> <li>Lower capital cost than laser</li> <li>Coverage area</li> </ul>	<ul style="list-style-type: none"> <li>Downtime for coil change</li> <li>Quenchant required</li> <li>Part distortion</li> <li>Coil placement critical</li> <li>Large thermal penetration</li> <li>EM forces may spoil surface</li> <li>Fabrication of complex coils for specific processes</li> </ul>
Flame	<ul style="list-style-type: none"> <li>Cheap, flexible and mobile process</li> </ul>	<ul style="list-style-type: none"> <li>Poor reproducibility</li> <li>Lacks rapid quench</li> <li>Component distortion likely</li> <li>Environmental problems</li> </ul>
Arc (TIG)	<ul style="list-style-type: none"> <li>Relatively cheap and flexible process</li> </ul>	<ul style="list-style-type: none"> <li>Section thickness limited</li> <li>Large thermal penetration</li> <li>Stirring takes place</li> <li>Poor control to avoid melting</li> </ul>
Electron beam	<ul style="list-style-type: none"> <li>Minimal distortion, selective hardening and no quenchant required</li> </ul>	<ul style="list-style-type: none"> <li>High equipment cost</li> <li>Requires vacuum</li> <li>Low production rate</li> <li>High processing costs</li> </ul>

ME 677: Laser Material Processing  
Instructor: Ramesh Singh



# Thermomechanical Diffusion Processes

## 2. Thermochemical Diffusion Processes



# Laser Heat Treatment

- The initial goal of laser heat treatment was selective surface hardening for wear reduction
- Now it is also used to change metallurgical and mechanical properties
- There are many competing processes in the large area surface heat treatment
- The laser usually competitive due to lack of distortion and high productivity



# Laser Surface Applications

- Hardness increase
- Strength increase
- Reduced friction
- Wear reduction
- Increase in fatigue life
- Surface carbide creation
- Creation of unique geometrical wear patterns
- Tempering



# Features

- Laser heat treatment is used on steels with sufficient carbon content to allow hardening and cast irons with a pearlite structure.
- An absorbing coating is usually applied to the metal surface to avoid unnecessary power loss by reflection
- The absorption coefficient can also be increased by allowing a polarised beam with the electric vector in the plane of incidence, to be reflected at the Brewster angle (approximately  $8^\circ$  for metals)
- This leads to a unique process for transformation hardening inside small holes - such as valve guides.

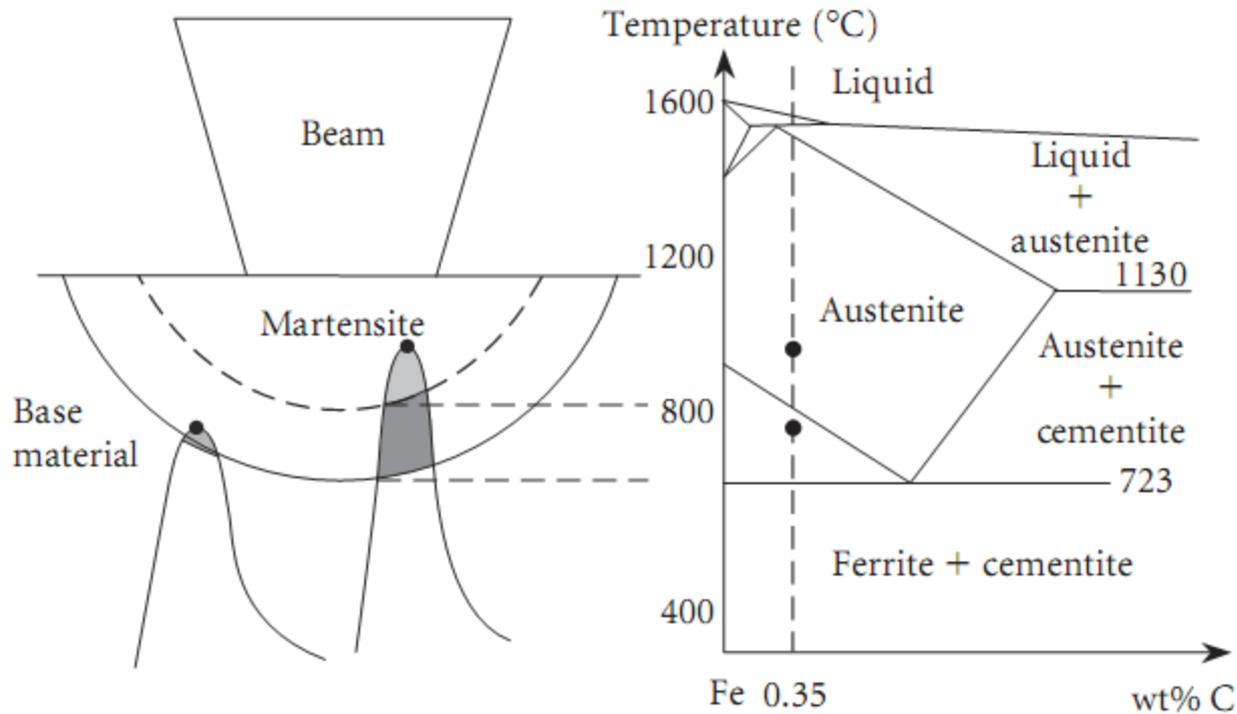


# Hardening Mechanism-Hypoeutectoid

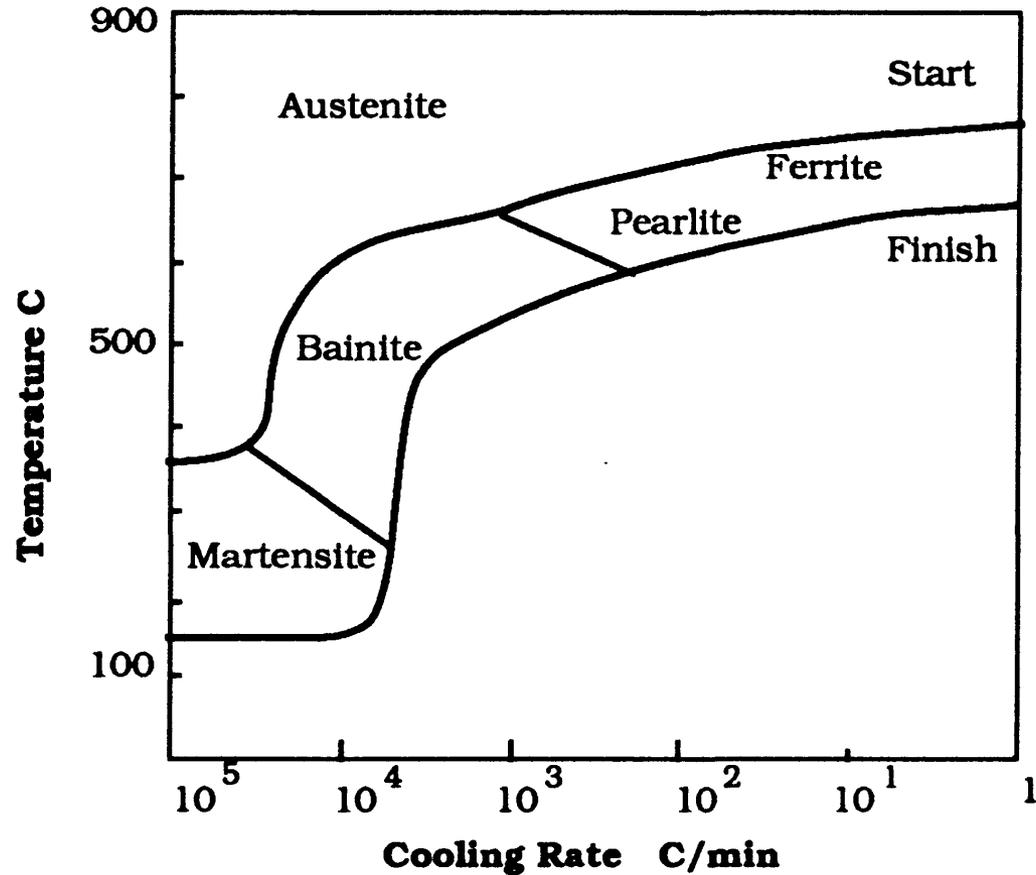
- Consider the microstructure of a hypoeutectoid steel containing 0.35% carbon. It consists of pearlite colonies surrounded by proeutectoid ferrite.
- On heating, pearlite transforms to austenite by dissolution of the cementite lamellae, followed by growth of the austenite transformation front into regions of high carbon concentration, at a rate controlled by carbon diffusion between the lamellae
- Ferrite transforms by nucleation and growth of austenite at internal ferrite grain boundaries, at a rate controlled by carbon diffusion over greater distances associated with the size of the ferrite colonies
- The phase diagram shows that under equilibrium conditions, pearlite begins to transform to austenite at  $723^{\circ}\text{C}(\text{Ac}1)$ , and that transformation of ferrite is complete at about  $800^{\circ}\text{C}(\text{Ac}3)$ .
- The high heating rate experienced during laser heating (on the order of  $1000 \text{ K s}^{-1}$ ) results in superheating of  $\text{Ac}1$  and  $\text{Ac}3$ , typically by about  $30$  and  $100^{\circ}\text{C}$ , respectively.
- The heat is conducted to the bulk at a very fast rate which results in surface quenching and martensitic hardening.



# Hardening



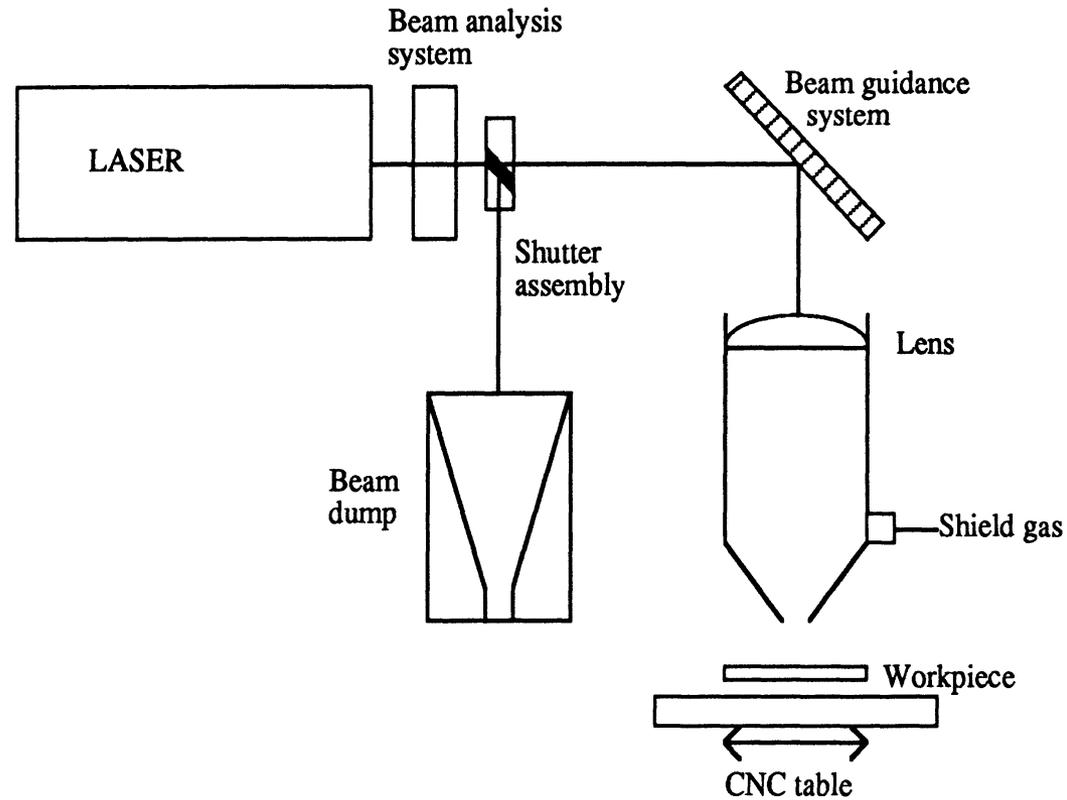
# Cooling Transformation



ME 677: Laser Material Processing  
Instructor: Ramesh Singh



# Schematic of the Setup



ME 677: Laser Material Processing  
Instructor: Ramesh Singh



# Process Description

- The laser beam is defocussed or oscillated to cover an area such that the average power density has a value of  $10^3 - 10^4 \text{W/mm}^2$
- Using these power densities a relative motion between the workpiece and the beam of 5 -50 mm/s will result in surface hardening
- If undesired surface melting occurs, relative motion should be increased
- A decrease in power density will produce the same effect
- If no or lower than expected level of hardening occurs the relative motion should be decreased or power density should be increased
- The depth of hardening depends upon thermal diffusion and hence the heating time ( $D/V$ ) and temperature
  - where  $D$  is the spot size on the workpiece and  $V$  is the traverse speed
  - Temperature is driven by input power intensity
  - Hardening is a function of  $(P/DV)$



# Hardening Plots

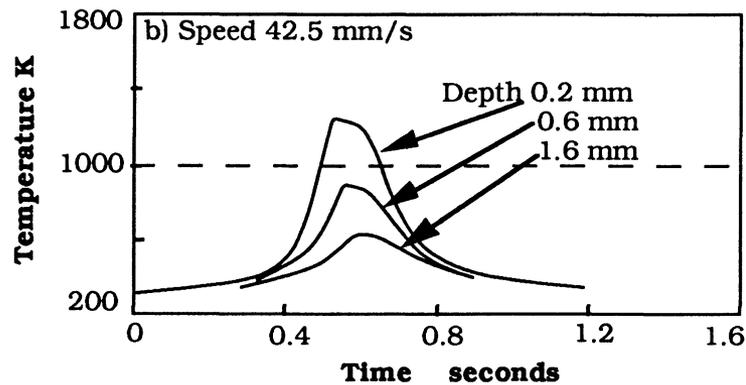
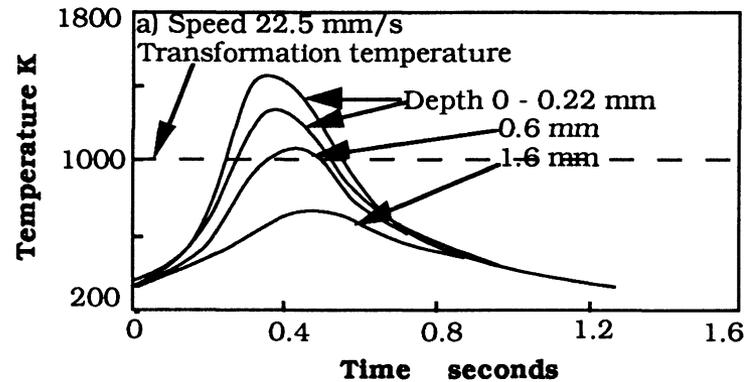


Fig. 6.5. Theoretically predicted thermal cycles during laser heating of En8 steel (power = 2kW, beam radius = 3mm and reflectivity = 0.4) (4).

ME 677: Laser Material Processing  
Instructor: Ramesh Singh

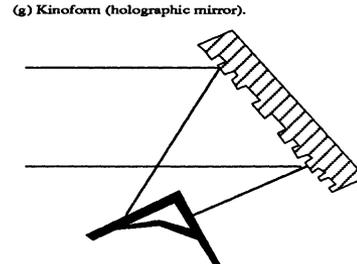
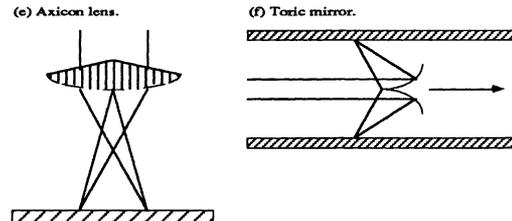
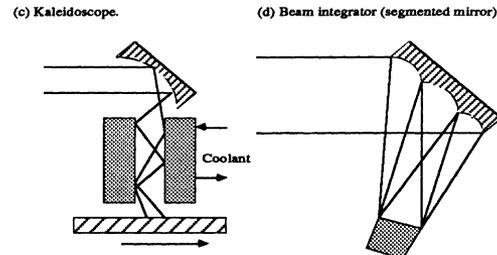
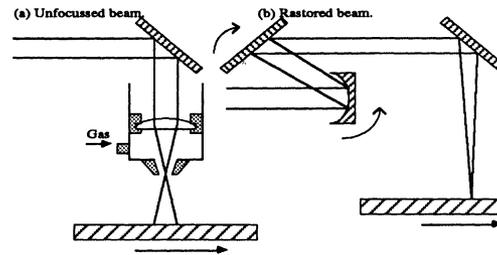


# Heat Flow

- The ideal power distribution is one which gives a uniform temperature over the area to be treated
- The heating effect is dependent on the edge cooling and surface heating:
  - $P/D$  and not  $P/D^2$  (where P is the incident absorbed power)
- Methods of spreading the beam to simulate this are illustrated in
- Defocussed high power multimode beams (top hat mode)
- One or two axis scanning beams (dithered zig zag mode)
- Kaleidoscopes
- Segmented mirrors
- Special optics (axicon lenses, toric mirrors and kinoforms)



# Methods of Providing Uniform Power



Instructor: Ramesh Singh



# Heat Flow

- Idealized models of 1D heat transfer.
- A simple test to determine if this representation can be used to examine the cross-section of a heat treated sample
- If the bottom of the hardened zone is flat and parallel to the surface under the central part of the cross-section, then the one-dimensional analysis will predict the temperatures in the heated material with reasonable accuracy



ME 677: Laser Material Processing  
Instructor: Ramesh Singh



# Heat Flow

- Transformation hardening with no surface melting is the simplest process to model mathematically
  - There are no unknown convection or latent heat terms since there is no melt pool and surface heat losses follow the normal rules of convection and radiation
  - Empirical relationship between  $P / (DV)^{1/2}$  and the depth of hardness has been derived

$$d = -0.10975 + 3.02 \frac{P}{\sqrt{DV}}$$



# Austenitization

- The base structure consists of a non-homogeneous distribution of carbon
  - Ferrite
  - Pearlite
- Upon heating above the phase transformation temperature,  $A_{c1}$  temperature carbon starts to diffuse to achieve homogeneity within the austenite phase
- A solid solution of C in Fe is formed



# Diffusion in Austenization

- The rate of diffusion is described by similar equations to that for heat flow, but is usually much slower

$$\frac{\delta c}{\delta t} = D_{AB} \left[ \frac{\delta^2 c}{\delta x^2} + \frac{\delta^2 c}{\delta y^2} + \frac{\delta^2 c}{\delta z^2} \right]$$

- Diffusivity of C in austenite is given by,

$$D = 1 \times 10^{-5} e^{-9.0/T} \text{ m}^2/\text{s}$$

- Diffusivity of C in ferrite is given by,

$$D = 6 \times 10^{-5} e^{-5.3/T} \text{ m}^2/\text{s}$$



# Austenitization

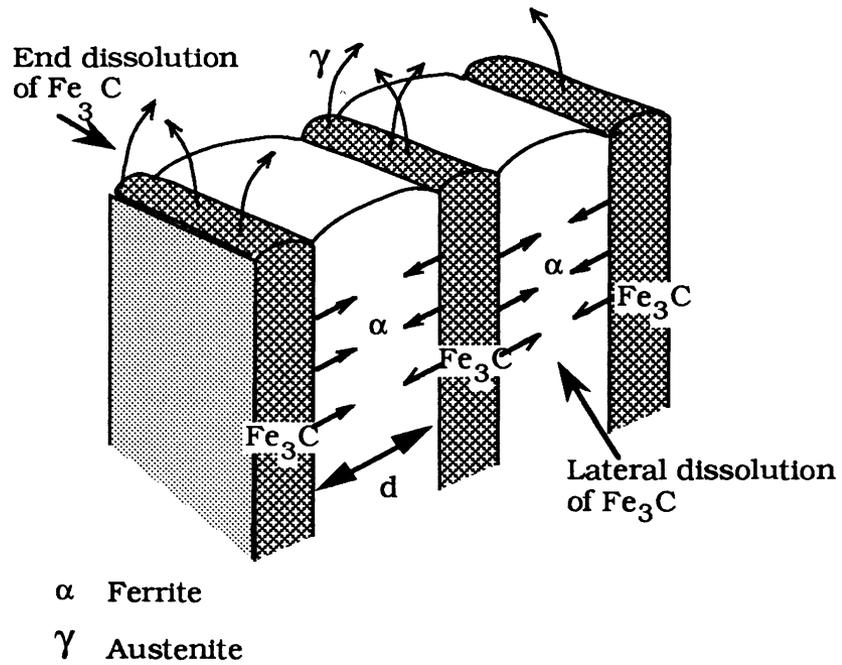
- When austenitization has occurred the carbon moves by diffusion down concentration gradients
- The time for diffusion within the austenitic lattice varies with position within the laser treated zone
- In laser transformation hardened zones there is always a region around the edges, if not throughout, where the carbon has not fully diffused
- The resulting structure is a non-homogeneous martensite
- It is expected that the higher carbon levels in certain regions would lead to higher hardness levels and therefore better overall wear resistance.



# Mechanism of Transformation

- On rapid heating, pearlite colonies first transform to austenite
- Then carbon diffuses outwards from these transformed zones into the surrounding ferrite increasing the volume of high carbon austenite.
- On rapid cooling these regions of austenite which have more than a certain amount of carbon (e.g. 0.05 %) will quench to martensite
- If the cooling rate is sufficiently fast although retained austenite may be found if the carbon content is above a certain value ( $>1.0$  %).
- The required rate of cooling is indicated by constant cooling curves,





# Diffusion

- The transformation of the pearlite is thought to proceed by diffusion from the cementite plates into the ferrite plates, possibly starting from one end of a pearlite colony
- This time dependent process does not take long but is sufficient to necessitate some superheat above the austenitization temperature,  $A_{c1}$ , to allow it to proceed during laser treatment.
- The superheat, and therefore the extent of the diffusion process, is thus slightly affected by the prior size of the pearlite colonies.
- These colonies, on transformation, become austenite having 0.8 % carbon
- Carbon diffuses down the concentration gradient into the ferrite regions where there is virtually no carbon.
- The ferrite regions may also have transformed to the FCC (face centred cubic) structure of austenite.
- The extent of homogeneity of the resultant martensite depends upon the size of the prior ferrite regions and the processing conditions



# Hardened Zone

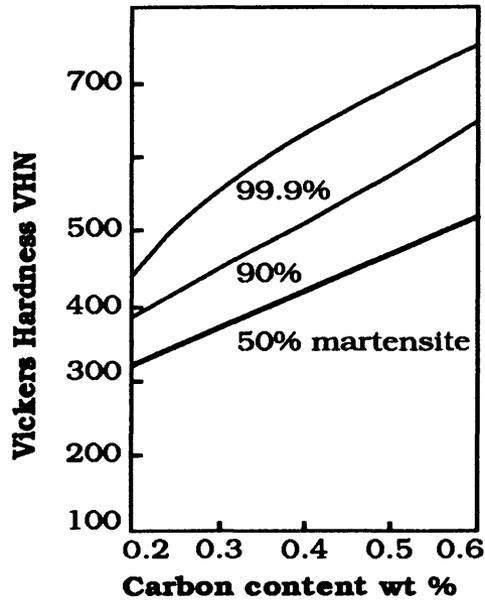


Fig. 6.11a. Average relationship between carbon content and hardness for steels containing different amounts of untempered martensite (13).

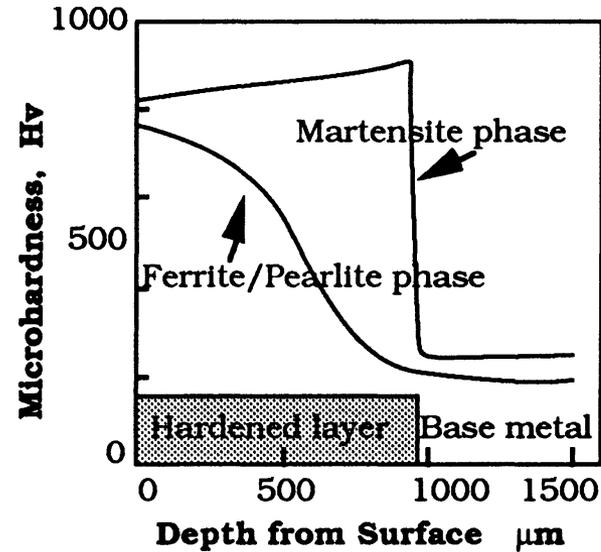
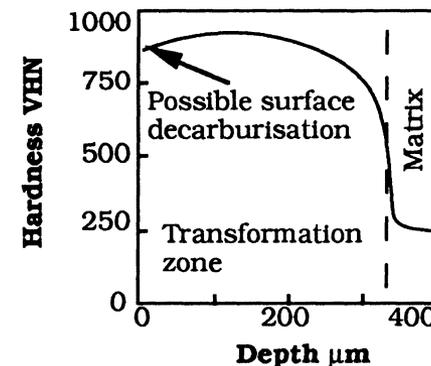


Fig. 6.11b. Micro hardness distribution in a non homogeneous hardened specimen (14).



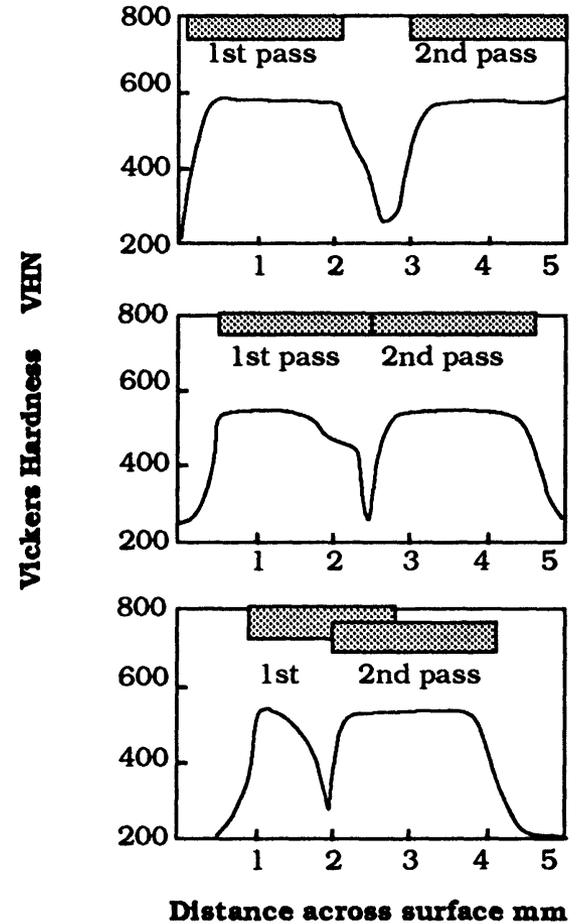
# Properties of Hardened Steels- Hardness

- This depends upon the carbon content
- It has been found that the laser hardness value may be slightly higher than that found for induction hardening
- This difference is probably due to the shallower zone in the laser process allowing
  - A faster quench
  - A greater restraint and hence higher residual compressive stress



# Patterned Surfaces

- Overlapping successive tracks induces a thermal effect in the neighboring tracks so that there is some back tempering.
- This is not necessarily undesirable since it allows space for oil and wear debris
- Patterned hardened surfaces have not been studied extensively as wear surfaces mainly because prior to the laser they were difficult to make
- The laser can make patterned surfaces easily and therefore opens a whole new study in tribology



# Fatigue

- In steels and cast irons there is a residual compressive stress on transformation hardening due to the volume expansion on the formation of martensite (approximately 4% for 0.3 wt%C steel)
- This effect is particularly pronounced in the shallower hardened zones formed with the laser due to the greater restraint for such treatment
- Fatigue cracks are generally initiated at the surface by tensile stresses thus the fatigue load must be sufficient to overcome this residual compressive stress before a crack can propagate
- Improved fatigue life compared to induction hardening has been reported with laser heat treatment

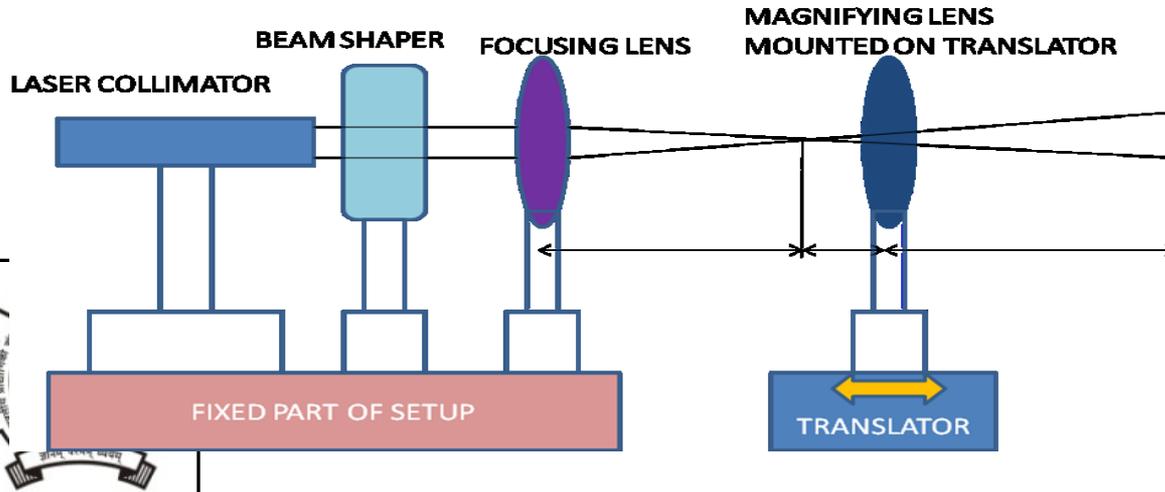
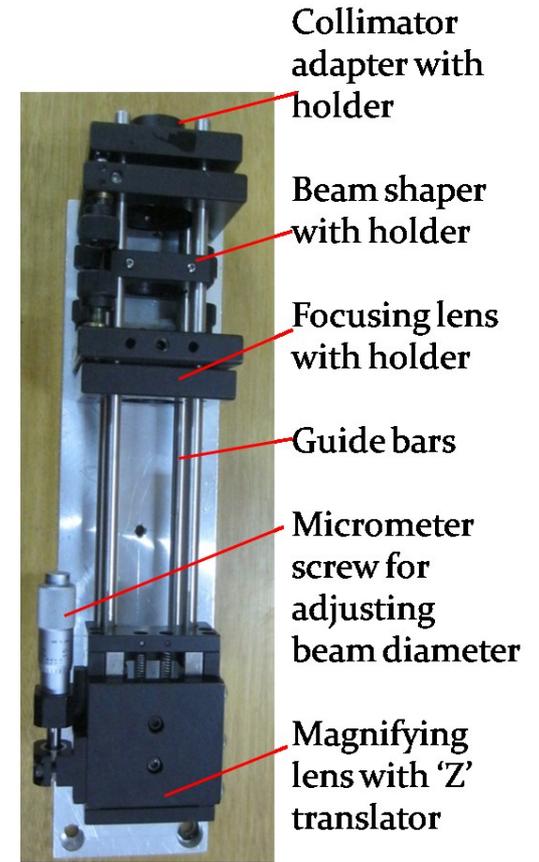


# Wear Resistance

- Wear resistance has also been found to improve with laser treatment compared to oil or water quench.
- On SK5 steel the pin on disc wear resistance of laser treated surfaces was found to be twice that of an induction hardened surface.



# Laser hardening @ IITB -



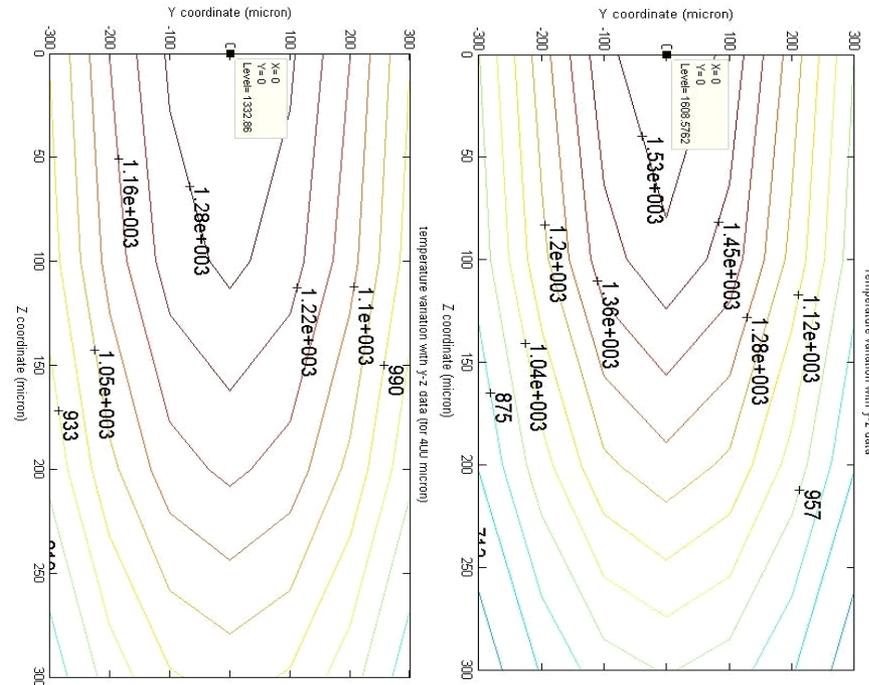
Indian Patent Application No. 442/MUM/2011 Filed on 17 February 2011

Method and device for generating laser beam of variable intensity distribution and variable spot size

# Temperature plot & micrographs in laser hardening

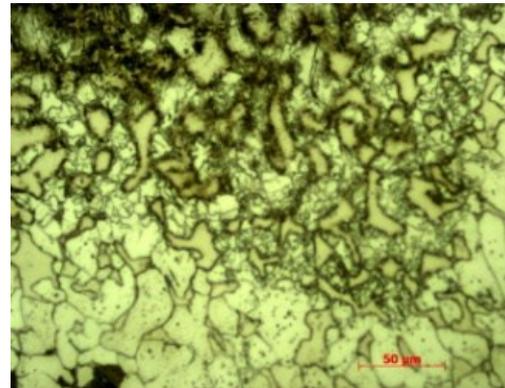
$$T - T_0 = \frac{2P}{8\pi^2 \sigma^2 K} \int_0^t \frac{dt'}{(t-t')} \exp\left[-\frac{z^2}{4a(t-t')}\right] \int_{-\sigma}^{\sigma} \exp\left[-\frac{((x-vt')-x')^2}{4a(t-t')}\right] dx' \times$$

$$\left[ -\operatorname{erf}\left(\frac{y-\sqrt{\sigma^2-x'^2}}{2\sqrt{a(t-t')}}\right) + \operatorname{erf}\left(\frac{y+\sqrt{\sigma^2-x'^2}}{2\sqrt{a(t-t')}}\right) \right]$$

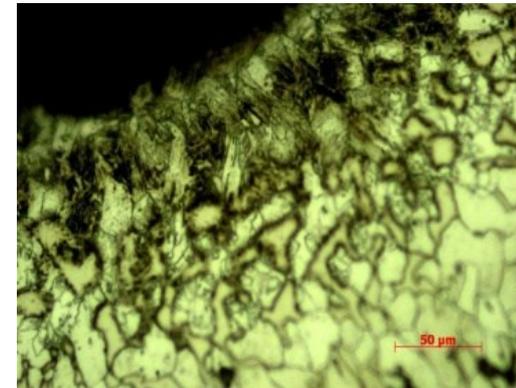


(a)

(b)



(a)



(b)



# Hardness Calculation & Hardness Plot

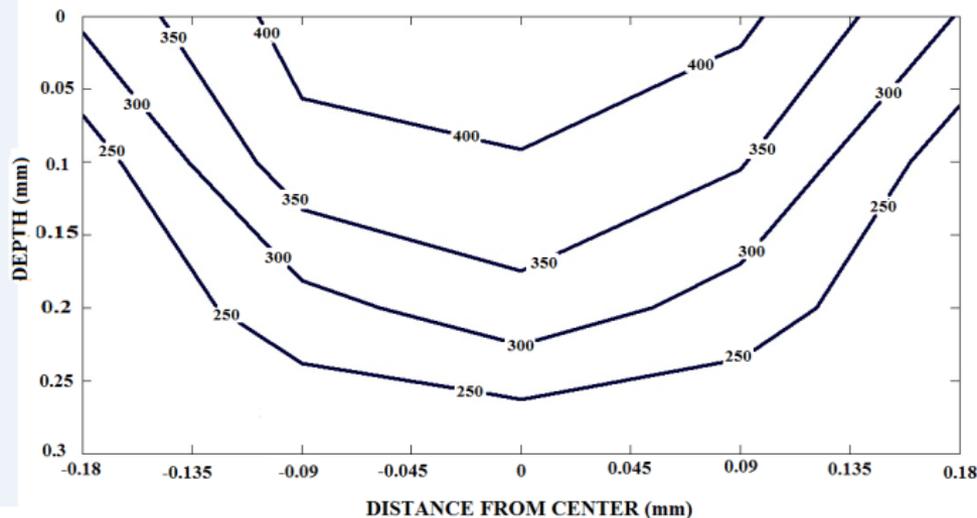
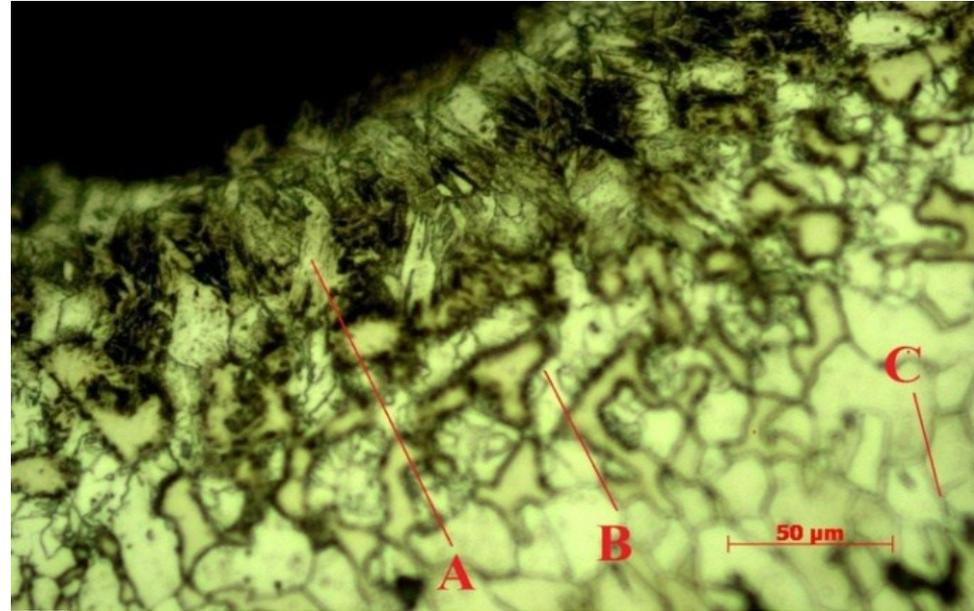
$$\alpha = \sqrt[3]{(R \cdot T_p / Q)}$$

$$\lambda = 2 \pi \alpha \tau \exp(-Q / (R \cdot T_p))$$

$$f = f_m - (f_m - f_i) \exp\left[-\left[\frac{12 f_m^2}{\sqrt{\pi} \cdot \lambda} \ln\left(\frac{C_e}{2 C_c}\right) \sqrt{D \tau}\right]^2\right]$$

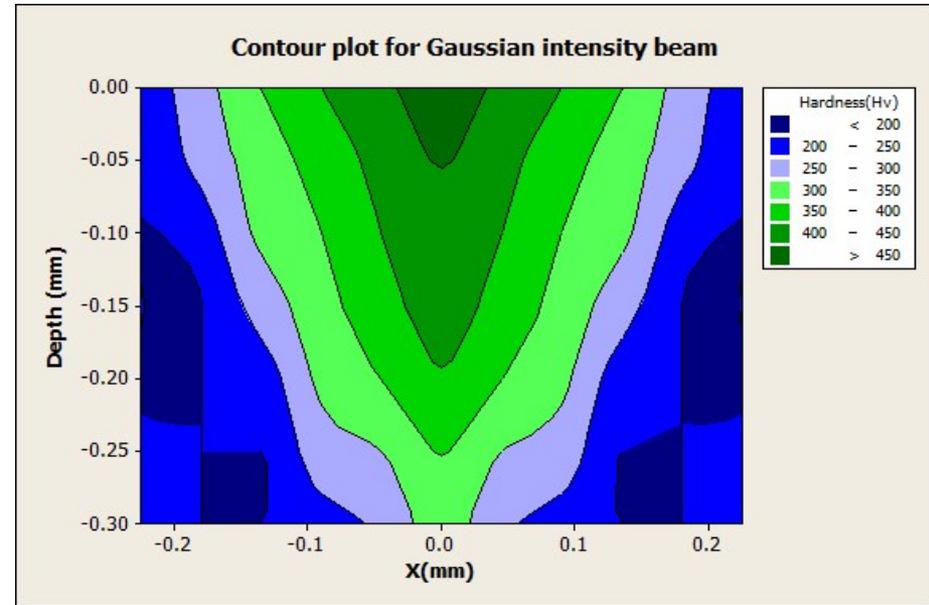
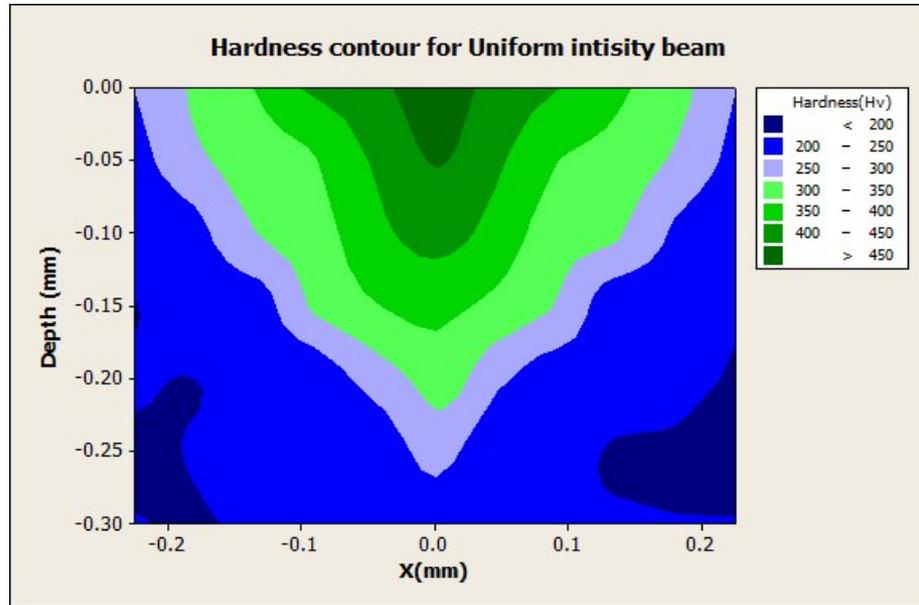
$$H = f H_m + (1 - f) H_f$$

$$H = 1667 C - 926 \frac{C^2}{f} + 150$$



Material Processing  
Ramesh Singh

# Comparison of Gaussian and Uniform Intensity Beam



Annealing due to successive pass overlap

Flat top beam

Hardened zone

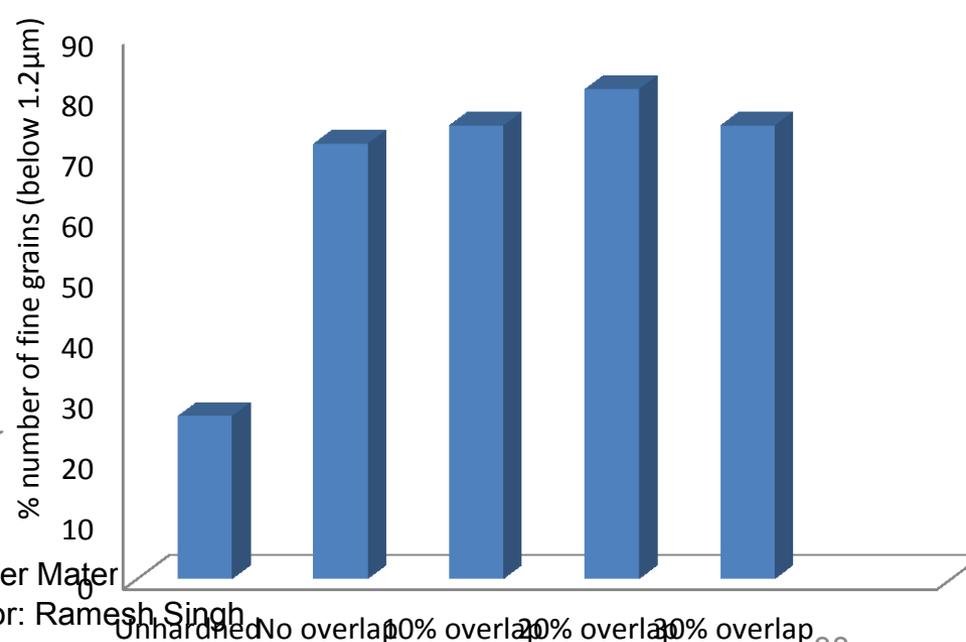
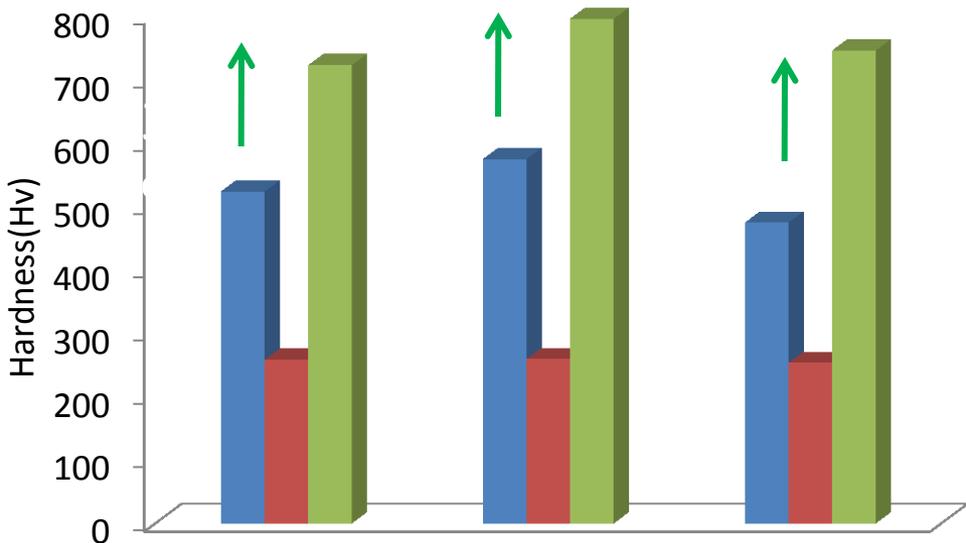
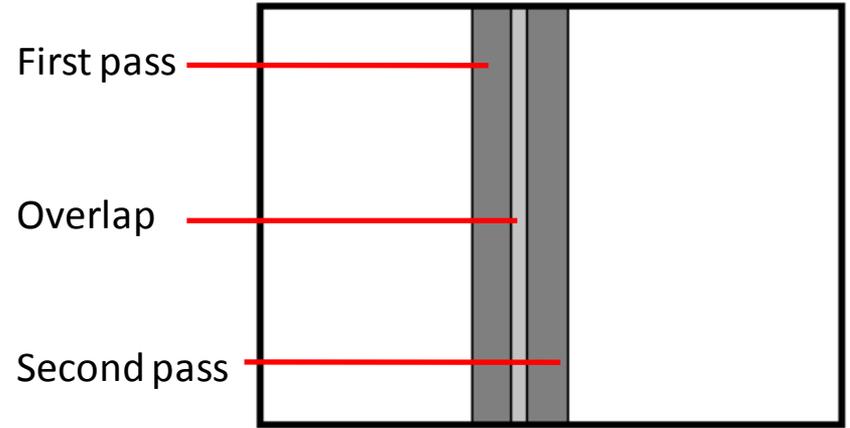
Gaussian beam

ng



# Overlap Study

- 
- 



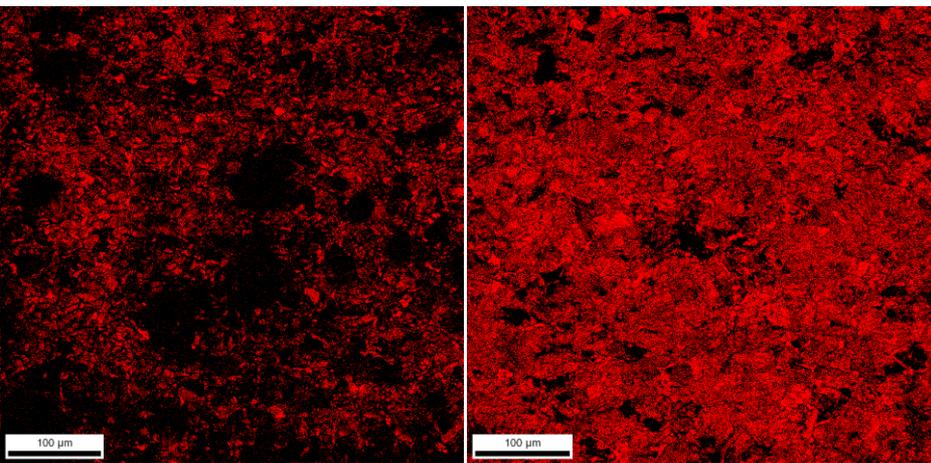
10% Overlap      20% Overlap      30% Overlap

■ First pass   ■ Overlap   ■ Second pass

ME 677: Laser Mater  
Instructor: Ramesh Singh

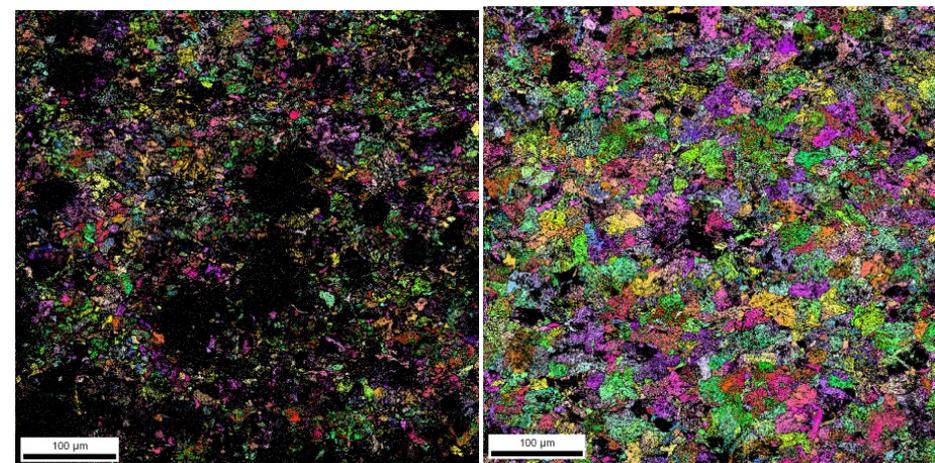
Unhardened No overlap 10% overlap 20% overlap 30% overlap

# EBSD Results in First & Second Pass



(A) (B)

Phase map showing martensite in (A) specimen without overlap (B) Specimen with 20% overlap



(A) (B)

Inverse Pole Figure (IPF) showing martensite in (A) specimen without overlap (B) Specimen with 20% overlap

Increase in martensite and finer grain formation in second

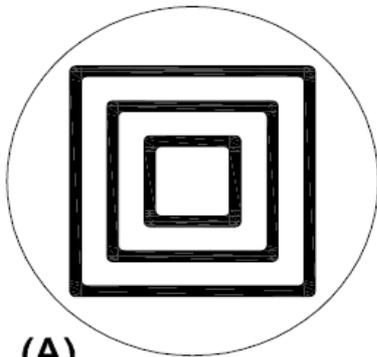


ME 677: Laser Material Processing  
Instructor: Ramesh Singh

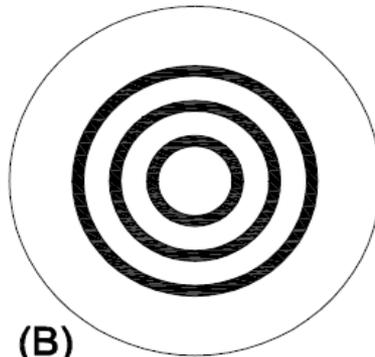
# Wear Test

## Objectives:

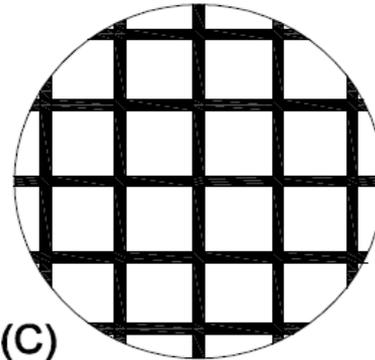
- To find effect of micro-scale hardened patterns on wear resistance
- To compare wear of different hardened geometries & to find out optimum hardened geometry



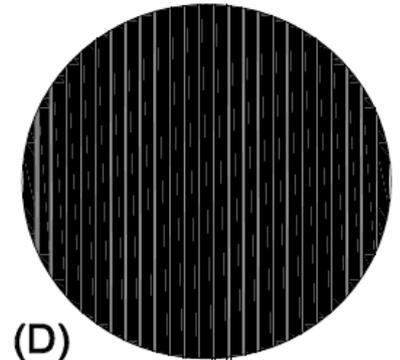
(A)



(B)



(C)



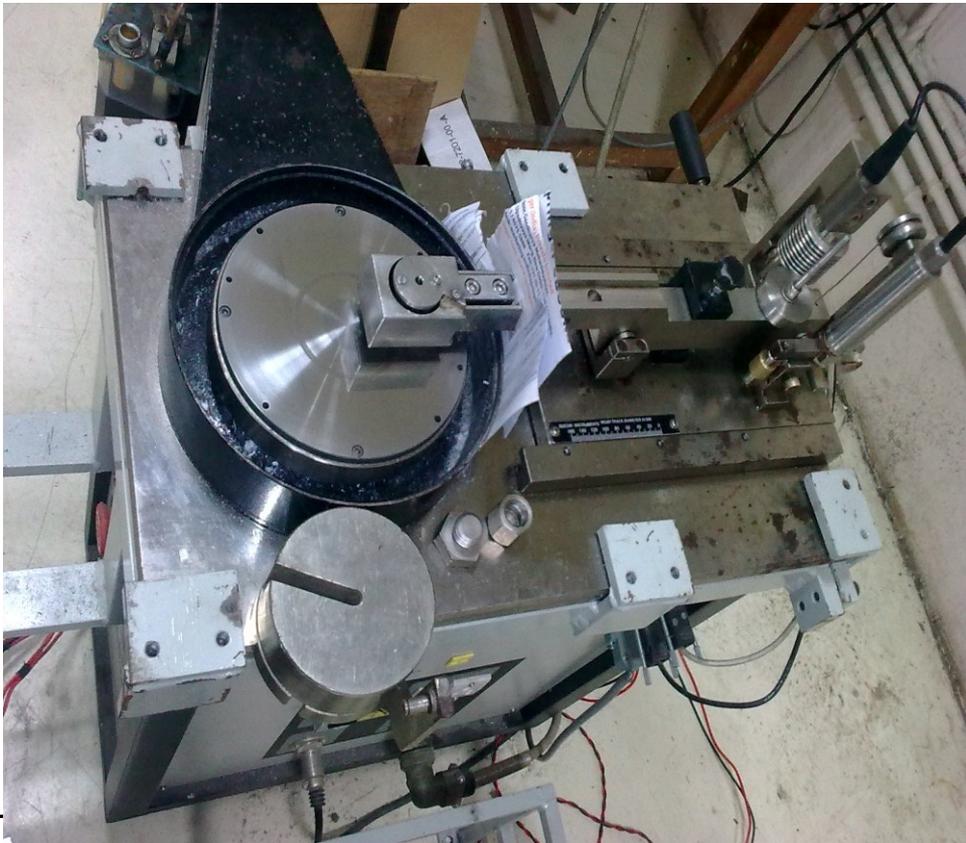
(D)

Different types of hardened patterns

Specimen size of diameter 10 mm and beam with size of 300  $\mu\text{m}$



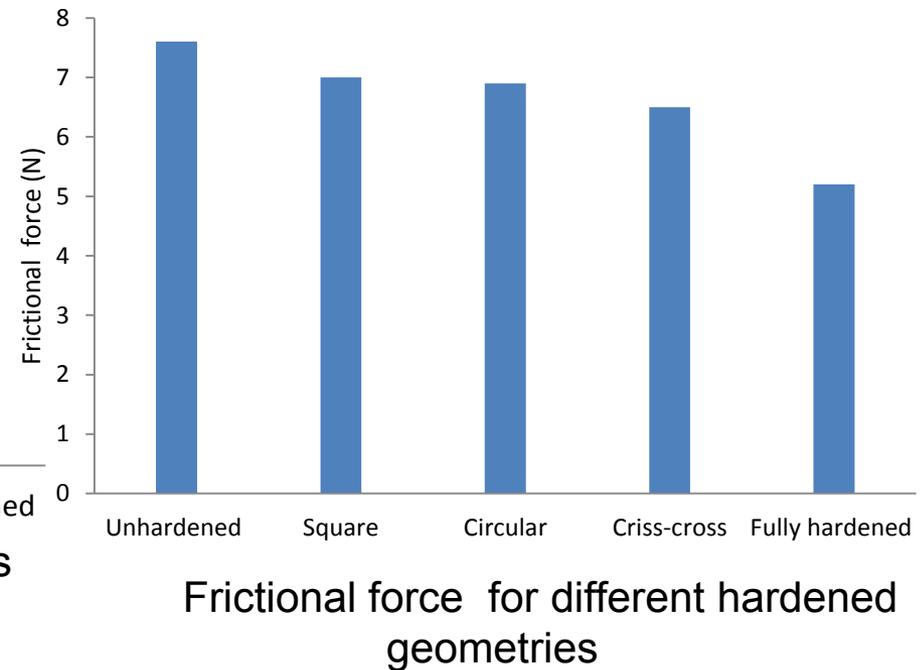
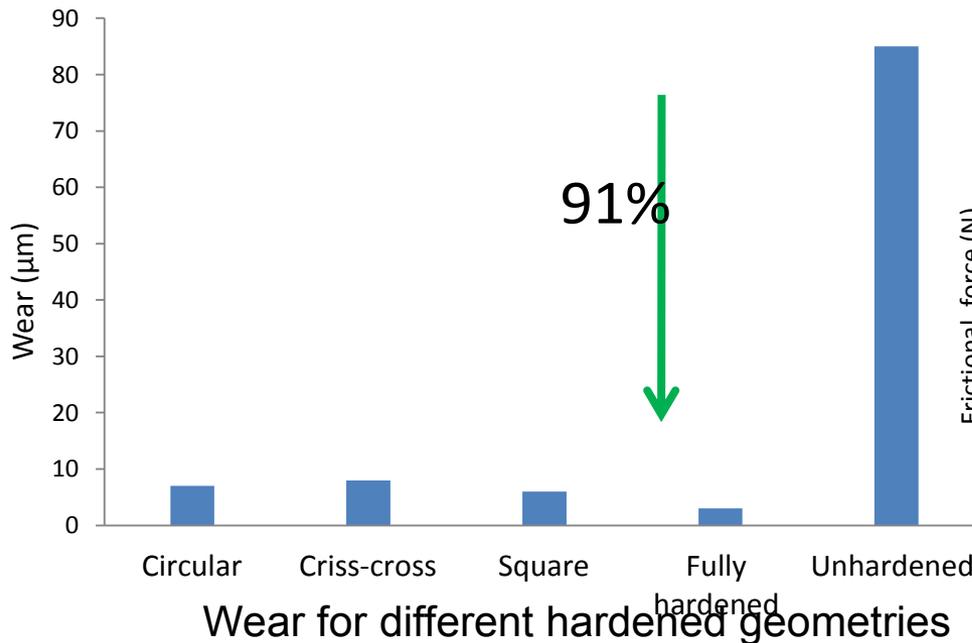
# Pin on Disk Setup



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

# Wear Test: Key Findings

- Wear resistance improve drastically because of hardening.
  - Whereas there is slight difference in wear observed in different hardened geometries.
  - Frictional force is inversely proportional to 'percent area hardened' .
- \*\*\*\* Wear of fully hardened (overlapped) specimen is 58% less than other hardened patterns(i.e. Square, circular, criss-cross).

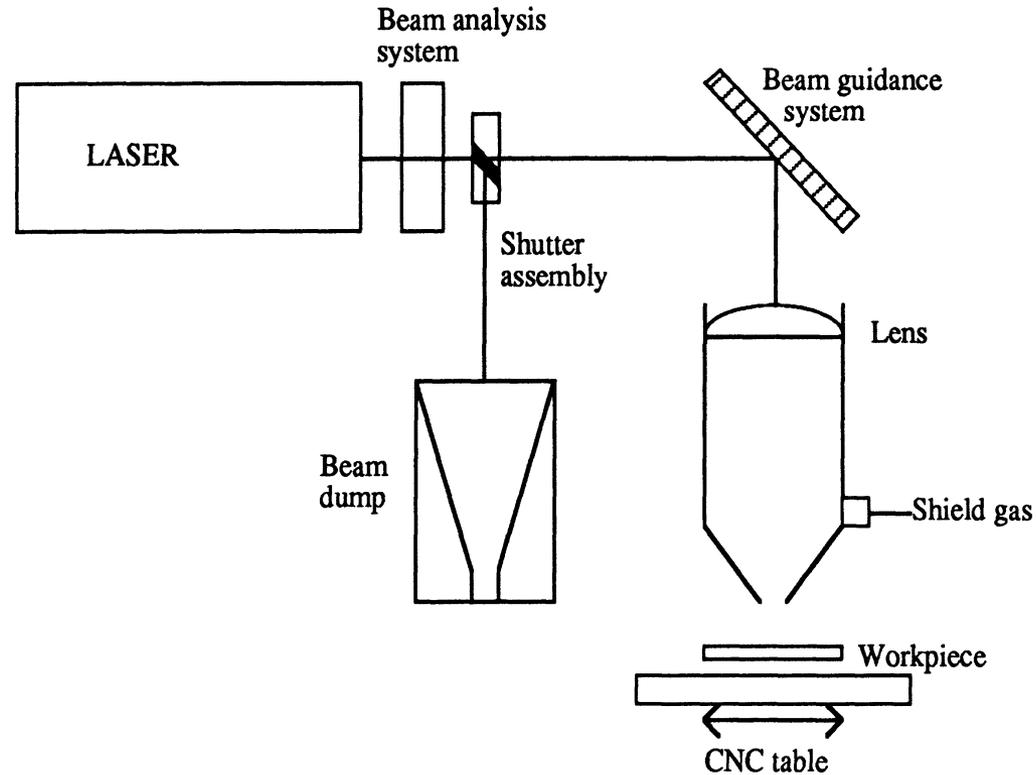


# Laser Surface Melting

- For surface melting the experimental arrangement is similar to that for transformation hardening
- Unlike hardening, a focused or near focused beam is used
- The surface to be melted is shrouded by an inert gas



# Setup for Laser Surface Melting



# Competing Processes

Process	Characteristics
Laser	High capital cost, localised heating of sample, rapid solidification of melt zone to give fine recrystallised grain structure, and good homogeneity. Controllable surface roughness. Power density $10^2 - 10^4 \text{ W/cm}^2$ .
Flame	Cheap capital cost, poor reproducibility, no fast quench available, environmental problems and sample distortion . A flexible and mobile process.
Plasma	Medium capital cost, very low heat input to sample.
TIG	Limited section thickness, electromagnetic stirring, weld bead may be rough, large thermal penetration and medium heat input.
Induction	Cheaper than laser, large thermal penetration, electromagnetic force may spoil surface, fast processing rate, deep case possible and fast area coverage.



# Characteristics

- Moderate to rapid solidification rates producing fine near homogeneous structures.
- Little thermal penetration, resulting in little distortion and the possibility of operating near thermally sensitive materials
- Surface finishes of around 25 microns are fairly easily obtained signifying reduced work after processing.
- Process flexibility, due to software control and possibilities in automation.



# Issues in Laser Surface Melting

- The following are key issues in laser surface melting
  - controlling the reflectivity
  - shaping the beam
  - shrouding the melt pool
- Reflectivity is difficult to control due to the melting process itself causing variations in the surface reflectivity.
- The initial reflectivity can be controlled by having an anti-reflection coating, but this is usually removed by the melting process

• If the material becomes hot the reflectivity is reduced



# Metallurgical Issues

- There are three metallurgical areas of considerable interest:
  - cast irons
  - tool steels and
  - certain deep eutectics (which can form metallic glasses at high quench rates)
- All are essentially non-homogeneous materials which can be homogenised by laser surface melting



# Disadvantages

- Reasons of surface melting not very popular with industry
  - Surface melting is inferior to surface alloying'as the latter offers the possibility of vastly improved hardness, wear or corrosion resistance
  - The very high hardnesses achieved with cast irons and tool steels by laser surface melting are associated with some surface movement which may require some further surface finishing post treatment
  - This is not so easy to achieve due to high hardnesses obtained



# Materials Processed-Cast Iron

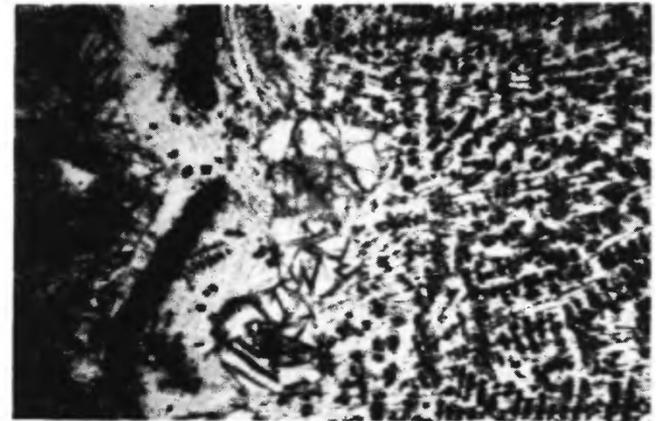
- Cast Iron is commonly used engineering material usually consists of an inhomogeneous structure of ferrite and graphite in various forms (flakes, spheres etc)
- On surface melting with a laser the hardening effects come from changes of graphite-to-cementite and austenite-to-martensite
- The precise value of the hardness depends on the extent of the carbon dissolution from the graphite giving a variation of hardness and structure with processing speed.
- The result is usually a very hard surface on one of the cheaper metals



# Micrograph of Laser Surface Melted CI

Three melt interface regions for laser surface melted flake graphite cast iron are:

1.  $\text{Fe}_3\text{C}$  dendrites in the ledeburitic fusion zone
2. High dissolved carbon (around 1 wt%) giving retained austenite with some martensite
3. Finally, full martensite and partially dissolved graphite flakes.



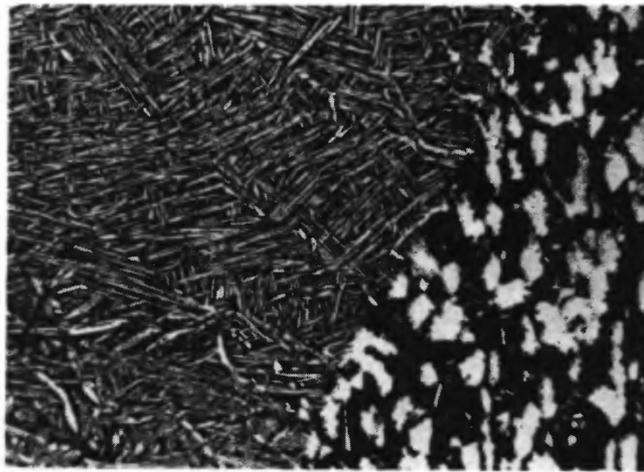
# Stainless Steel

- Fine structures are produced in both martensitic or austenitic stainless steels as expected from the high values of the cooling rate
- Without the phase expansion associated with the martensitic transformation austenitic steels have a residual tensile stress while single tracks of martensitic steel are usually under compression
- However the residual stresses becomes tensile when annealed by overlapping
- The residual tension adversely affects the stress corrosion properties and the pitting potential
- The laser melting and rapid solidification have differing effects on the pitting behavior of a series of ferritic steels
- Improved corrosion resistance of sensitized stainless steels has been noticed due to the finer structure reducing the tendency to intergranular corrosion



# Titanium

- Titanium and its various alloys can take up a variety of crystal forms. In laser surface melting rapid quench structures are formed which have a highly dislocated fine structures
- The process must be carefully shrouded due to the activity of titanium with oxygen



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

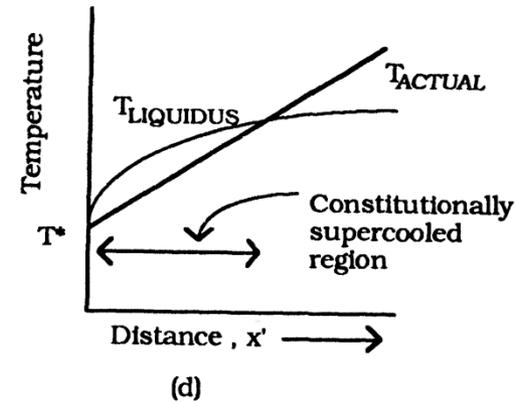
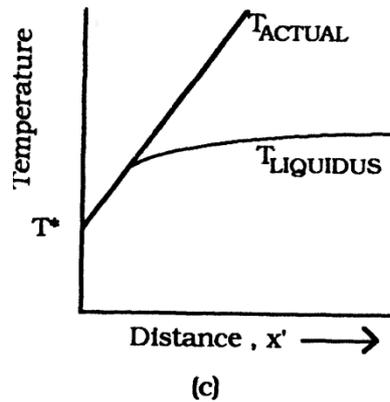
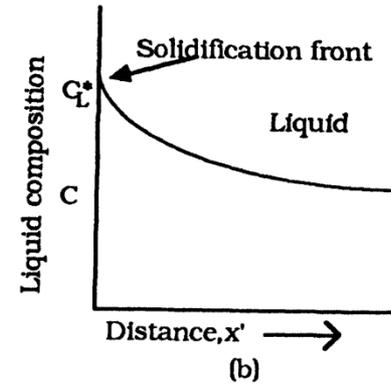
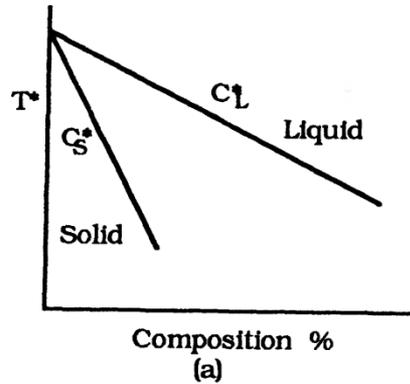


# Tool Steels

- These materials are usually hardened by a fairly long process of solution treatment to dissolve the carbides followed by a controlled quench to give a fine dispersion of carbides.
- These carbides do not temper as easily as martensite, hence these steels have a high hot hardness and are suitable for tools.
- In laser surface melting this dissolution is accomplished very swiftly producing a very hard, fine carbide dispersion with high hot hardness properties.
- The problem with the application of this process in production is that the laser melt track will have a surface waviness of around 10-25 microns and the track is very hard to machine.



# Solidification Mechanism



# Solidification Mechanism

- Solidification will proceed as either a stable planar front or as an unstable front leading to dendrites or cells
- The process which will occur depends on the occurrence of constitutional supercooling
- Constitutional supercooling is caused by the thermal gradient being less steep than the melting point gradient
- It is the result of partition effects taking place at the solidification



# Solidification

- Consider a mass balance on the solidification front, the gradient of the solute in the liquid at the solidification interface

$$\left[ \frac{dC_L}{dx} \right]_{x=0} = -\frac{R}{D_L} C_L^* (1-k)$$

- Constitutional supercooling is absent when the actual temperature gradient in the liquid at the interface,

$$G > (dT_L/dx)_{x=0}$$

$$\left[ \frac{dT_L}{dx} \right]_{x=0} = m_L \left[ \frac{dC_L}{dx} \right]_{x=0} \leq G$$



# Solidification

- Nomenclature

$C_L$  = Liquidus composition,  
 $x$  = Distance from the interface, m,  
 $T_L$  = Liquidus temperature, °C,  
 $R$  = Rate of solidification, m/s,

$D_L$  = Diffusivity,  $m^2/s$ ,

$C_L^*$  = Liquidus composition  
in equilibrium with solidus  
composition,  $C_S^*$ ,

$k$  = Partition coefficient,

$m_L$  = Slope of the liquidus,  $[dT_L/dC_L]$ ,

$G$  = Thermal gradient, °C/m.

$$\frac{G}{R} \geq - \frac{m_L C_S^* (1 - k)}{k D_L}$$

ME 677: Laser Material Processing  
Instructor: Ramesh Singh



# Scale of Solidification Structure

- If the dendritic or cellular structure is sufficiently fine then it is possible to approximate the liquid between the cells as being like a small stirred tank whose composition will be determined by the rate of diffusion out of the cell depleting the concentration of the cell, approximated by Fick's Second Law:

$$D_L \frac{\delta^2 C_L}{\delta y^2} = \frac{\delta C_L}{\delta t}$$

$$dC_L/dt = (dC_L/dT)(dT/dx)(dx/dt) = - GR/m_L$$

$$\left[ \frac{\delta C_L}{\delta y} \right]_{y=0} = - \frac{GR\lambda}{m_L D_L} \quad \text{and} \quad \Delta C_{L_{\max}} = - \frac{GR\lambda^2}{2m_L D_L}$$



# Material Flow Within the Melt Pool

- Surface shear force =  $\frac{\delta\sigma}{\delta x} = \frac{\delta\sigma}{\delta T} \frac{\delta T}{\delta x}$



# Laser Surface Alloying

- Surface alloying with a laser is similar to laser surface melting
- Another material is injected into the melt pool
- Laser surface alloying is also similar to surface cladding
- If the cladding process is performed with excess power then surface alloying would result
- Laser Surface Alloying is therefore one extreme of surface cladding.



# Process Characteristics

- The alloyed region shows a fine microstructure with nearly homogeneous mixing throughout the melt region
- Inhomogeneities are only seen in very fast melt tracks ( $\sim 0.5$  m/s)
- Most materials can be alloyed into most substrates. The high quench rate ensures that segregation is minimal
- Some surface alloys can only be prepared via a rapid surface quench, e.g. Fe-Cr-C-Mn
- The thickness of the treated zone can be from 1 -2000 microns
- Very thin and rapidly quenched alloy regions can be made using Q-switched Nd-YAG lasers



# Competing Processes

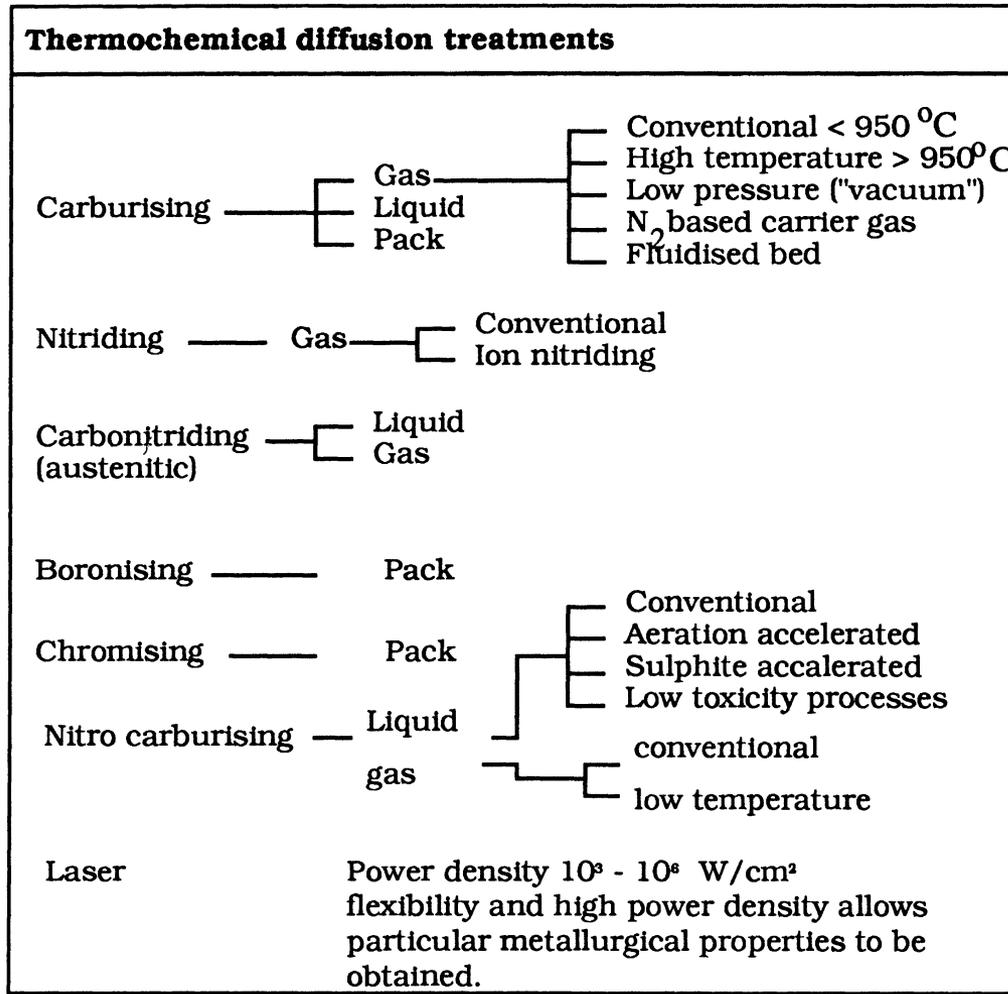


Fig. 6.24. Competing surface alloying methods.

MECH 577: LASER MATERIAL PROCESSING

Instructor: Ramesh Singh



# Process Variations

- The variations in processing are similar to those for surface melting except that an alloy ingredient has to be added
- The alloy can be placed in the melt zone by:
  1. Electroplating
  2. Vacuum evaporation
  3. Preplaced powder coating
  4. Thin foil application
  5. Ion implantation
  6. Diffusion, e.g. boronizing
  7. Powder blowing
  8. Wire feed
  9. Reactive gas shroud e.g.  $C_2H_2$  in Ar or just  $N_2$ .



# Description

- Laser surface alloying is capable of producing a wide variety of surface alloys
- The high solidification rate even allows some metastable alloys to be formed in the surface
- All this can be done by a non-contact method which is relatively easy to automate
- The laser offers precision in the placement of the alloy, good adhesion and vastly improved processing speeds.
- Provided
- The mixing is good and uniform if the speed is lower than a certain figure (e.g. 70mm/s for 2kW power)
- Some alloys suffer from cracking and porosity which may put restrictions on shrouding and preheat
- The surface profile can be quite smooth with a small ripple of around 10  $\mu\text{m}$

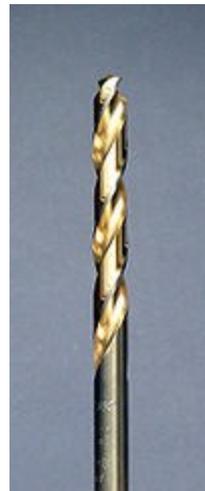


# Titanium

- Ti can be readily surface alloyed by carbon or nitrogen
- $N_2$  can be supplied by nitrogen shroud gas
- One of the beauties of these processes is that the hard carbide or nitride solidifies first as a dendrite which would be hard to remove
- The color effects on titanium are starting to attract the attention of the art world.



# Titanium Surface Coatings and Art



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

# Other Materials

- Cast iron
  - Surface alloying with Cr, Si or C are all possible methods to make relatively cheap cast irons into superficially exotic irons.
- Steel
  - Numerous systems have been explored
  - Cr by melting chromium plate
  - Mo , B, Ni
- Stainless steel
  - The carbon alloying of stainless steel by melting preplaced powder has been studied by Marsden
- Aluminium
  - Surface hardening of aluminium by alloying with Si, C, N and Ni has been demonstrated
- Superalloys
  - have been alloyed with chromium



# Summary – Laser Surface Alloying

- Surface alloying has many advantages and great flexibility
- The laser alloying process offers the possibility of surface compositional changes with very little distortion and surface upset
- This process has given engineers an option of the material of choice for the surface as well as the bulk

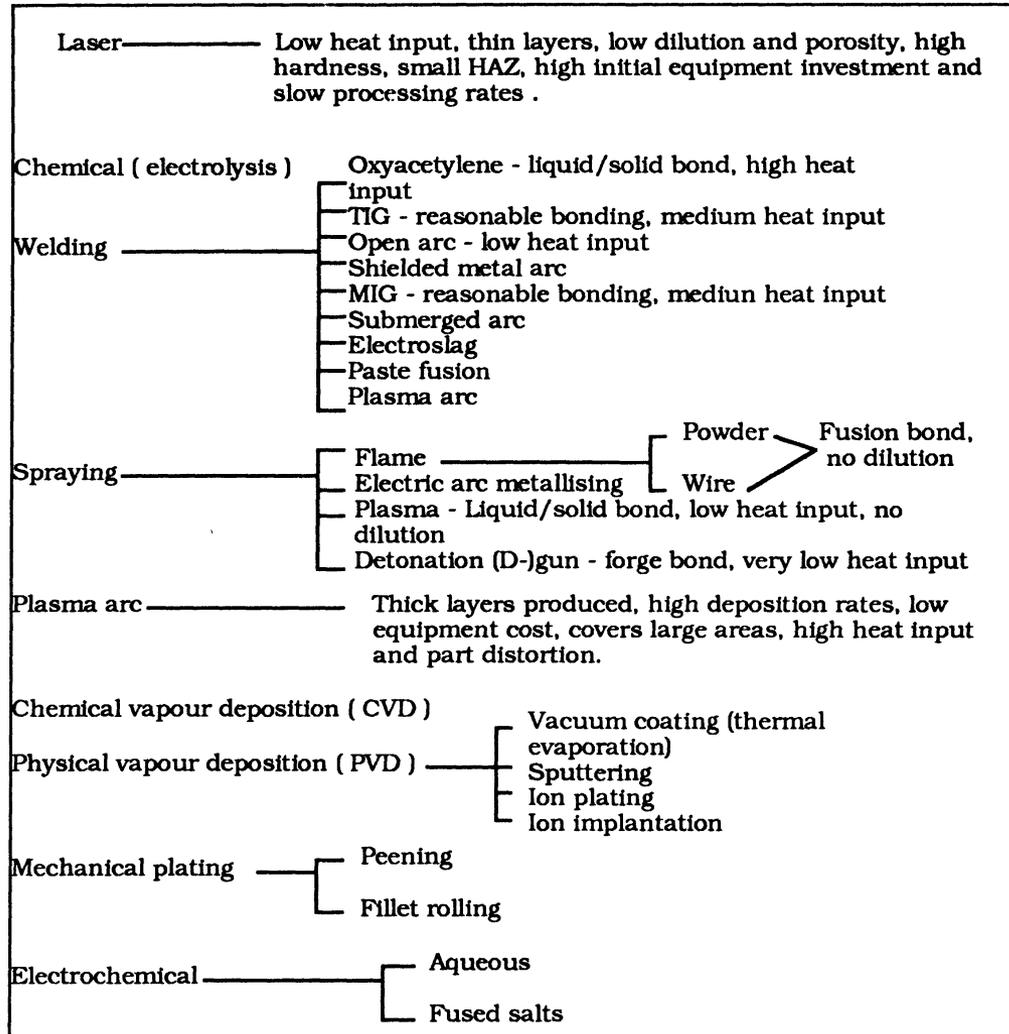


# Laser Surface Cladding

- The aim of most cladding operations is to overlay one metal with another to form a sound interfacial bond or weld without diluting the cladding metal with substrate material
- In this situation dilution is generally considered to be contamination of the cladding which degrades its mechanical or corrosion resistant properties



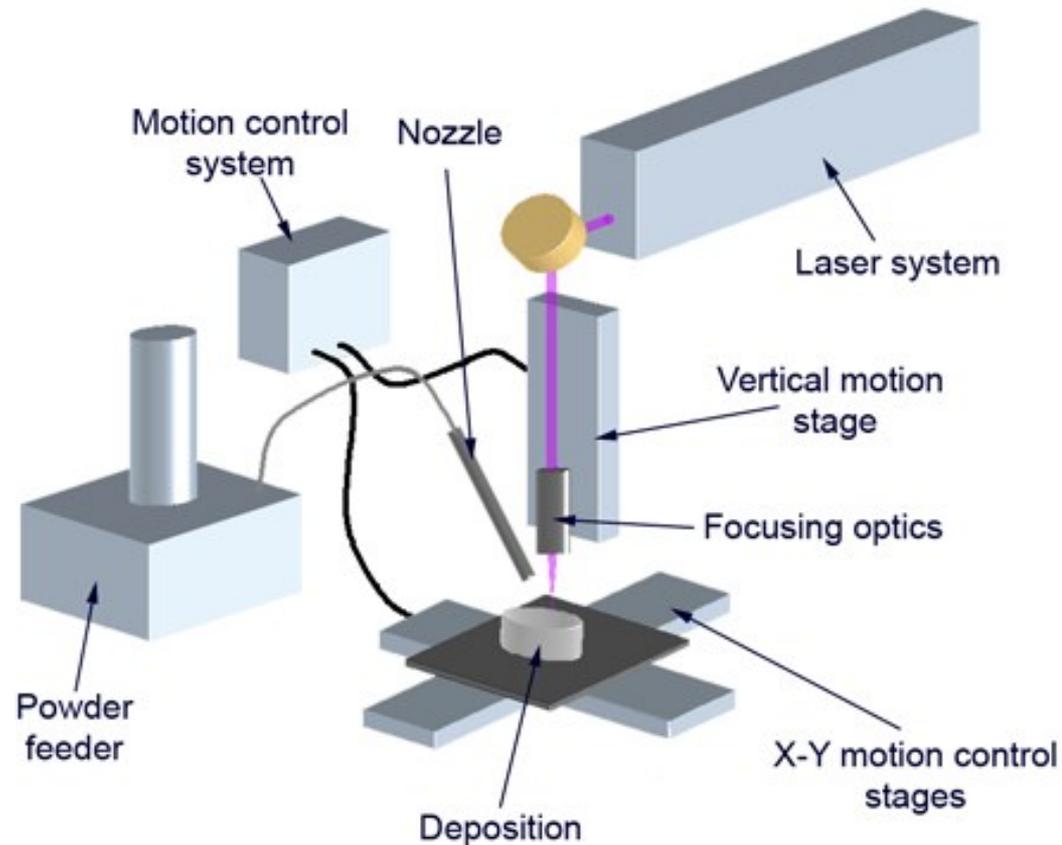
# Competing Methods



Instructor: Ramesh Singh



# Schematic of Laser Surface Cladding



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

# Laser Surface Cladding

- Thick section cladding ( $> 0.25$  mm) is frequently carried out by welding methods; substantial melting of the substrate is produced and therefore dilution can be a major problem
- Dilution is observed in tungsten inert gas (TIG), oxy-acetylene flame or plasma surface welding processes
- The melt pool is well stirred by electromagnetic, convective and Marangoni forces



# Process Characteristics

- This dilution necessitates laying down thicker clad layers to achieve the required clad property, but does have the advantage of a good interfacial bond
- Negligible dilution is achieved in other cladding processes which rely on either forge bonding or diffusion bonding
  - Forge bonds are made through the impact of high speed particles with the substrate (e.g. D-gun) or clad layer
  - Diffusion bonding occurs between a solid and liquid phase
- The fusion bond is usually the strongest and most resistant to thermal and mechanical shock, provided brittle intermetallics are not formed.



# Laser Cladding Techniques

- The main laser cladding methods are:
  - Melt preplaced powder
  - Blown powder
  - Decomposed vapor by pyrolysis
  - Photolysis as in Laser Chemical Vapour Deposition, (LCVD)
  - Local vaporisation as in Laser Physical Vapour Deposition (LPVD) or sputtering
  - Enhanced electroplating or cementation



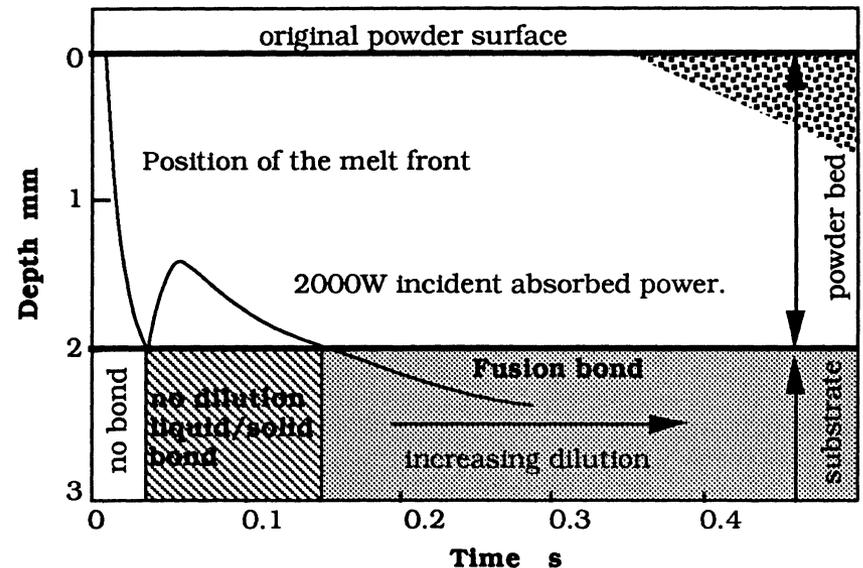
# Preplaced Powder Technique

- Cladding with preplaced powder is the simplest method provided the powder can be made to stick until melted, even while the area is being shrouded in inert gas
- Some form of binder is usually used. The preplaced powder method involves scanning a defocussed or rastered laser beam over a powder bed, which is consequently melted and welded to the underlying substrate
- Minimal dilution effects were observed for a wide range of processing parameters



# Modeling of Preplaced Powder

- Theoretical modeling of movement in the molten front has shown that the melt progresses relatively swiftly through the thermally isolated powder bed until it reaches the interface with the substrate
- At this point the thermal load increases due to the good thermal contact with the high thermal conductivity substrate causing resolidification.



ME 677: Lase  
Instructor

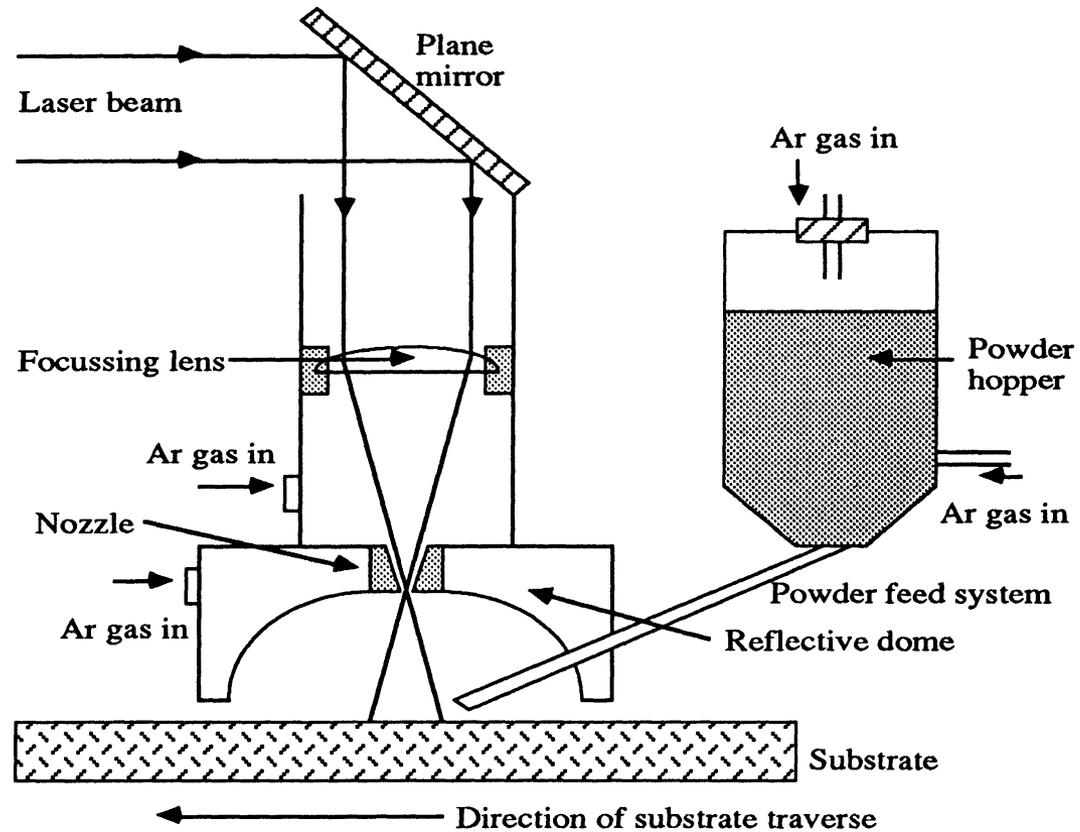


# Blown

- It is one of the few cladding techniques which has a well defined heated region, a fusion bond with low dilution and is adaptable to automatic processing
- A reflective dome such as this has been shown to recover around 40% of the delivered power
- This is necessary when cladding surfaces of variable reflectivity such as machined and shot blasted surfaces
- Blown powder cladding has the low dilution associated with forge bonded processes but the good surface strength and low porosity associated with the welding processes
- The covering rate for laser powers greater than 5 kW is attractive and when consideration of powder costs and after machining costs are taken into account then the process becomes economically comparable with other processes for covering large areas
- This process has the ability to cover very small areas and in particular areas near to thin walls which might be thermally sensitive, since there are no associated hot gas jets



# Schematic of Blown Powder Cladding



ME 677: Laser Material Processing  
Instructor: Ramesh Singh

